

2001064803

Matrix Failure Modes and Effects Analysis as a Knowledge Base for a Real Time Automated Diagnosis Expert System

Stephanie Herrin
Flight Equipment Engineering Branch
NASA Ames Research Center
Moffett Field, Ca. USA 94035

David Iverson
Spacecraft Data System Research Branch
Ames Research Center
Moffett Field, Ca. USA 94035

Lilly Spukovska
Computational Systems Research Branch
NASA Ames Research Center
Moffett Field, Ca. USA 94035

Abstract

Failure Modes and Effects Analysis contain a wealth of information that can be used to create the knowledge base required for building automated diagnostic Expert systems. A real time monitoring and diagnosis expert system based on an actual NASA project's matrix failure modes and effects analysis was developed. This Expert system was developed at NASA Ames Research Center. This system was first used as a case study to monitor the Research Animal Holding Facility (RAHF), a Space Shuttle payload that is used to house and monitor animals in orbit so the effects of space flight and microgravity can be studied. The techniques developed for the RAHF monitoring and diagnosis Expert system are general enough to be used for monitoring and diagnosis of a variety of other systems that undergo a Matrix FMEA. This automated diagnosis system was successfully used on-line and validated on the Space Shuttle flight STS-58, mission SLS-2 in October 1993.

Introduction

Formal reliability analyses, such as fault tree, digraph, or failure modes and effects (FMEA) analyses, are performed on many engineered systems. These analyses contain a wealth of information that can be used to help build automated diagnostic systems. A significant amount of effort can be saved by using reliability analysis information to build a diagnostic system since much of the knowledge engineering required for such a system will be done by the system engineers while performing the reliability analysis.

A real time monitoring and diagnosis system based on a matrix failure modes and effects analysis (FMEA) has been developed at NASA Ames Research Center. This system will be used with the Research Animal

Holding Facility (RAHF). The RAHF is a Space Shuttle Spacelab module designed at NASA Ames Research Center that is used to house and monitor animals in orbit so the effects of space flight and microgravity can be studied. A detailed matrix FMEA was initially performed on the RAHF. Subsequently a monitoring and diagnosis system based on the information contained in the RAHF matrix FMEA analysis was used to automatically monitor RAHF telemetry and help to detect, identify, diagnose, and repair problems that may occur in the RAHF system. The verification and validation of this system was successfully completed during the Space Shuttle flight 58, Spacelab Life Sciences-2 in October of 1993.

Matrix Failure Modes and Effects Analysis

Matrix failure modes and effects analysis (matrix FMEA) is a systematic method for tracing the effects of piece part failures on the overall system. A matrix FMEA decomposes the system into hierarchical indenture levels. The top indenture level represents the entire system. Lower indenture levels represent subsystems of the indenture level immediately above them. For each indenture level, the possible failures for each part and the effects of those failures are listed. The matrix FMEA traces the failure effects from lower indenture levels to higher indenture levels. Effects from lower indenture levels are treated as failures in the next higher level. Figure 1 illustrates the indenture level buildup in a matrix FMEA. Each horizontal row of a matrix represents possible failures of a given part, and the vertical columns show the effects of those failures [Ref. 1,2,3,4,5]. The diagram shows how the matrix FMEA traces failures from the lowest indenture level (circuit) to find their effects in the highest level (system).

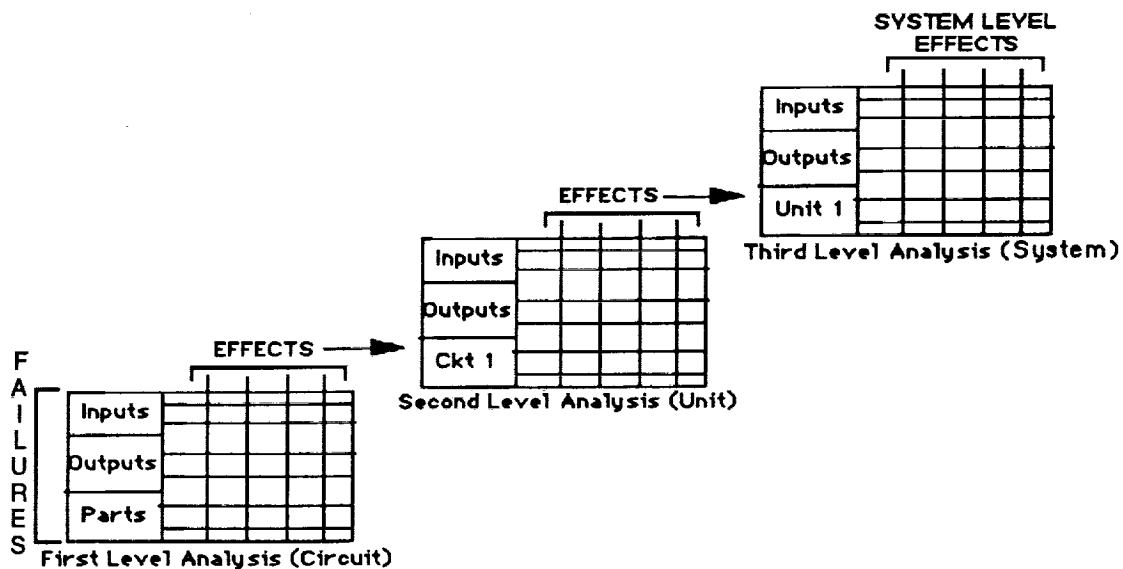


Figure 1: Matrix FMEA

Matrix FMEA Based Diagnosis

Matrix FMEA analysis organizes system failure information into structured cause and effect relationships. This structure provides a mapping from the matrix FMEA into a set of diagnostic rules [Ref. 6]. Rules are derived from the matrix FMEA by treating each failure at a given indenture level as a rule antecedent and each effect of that failure as a rule consequent.

This technique was used to build a RAHF diagnostic knowledge base for use with the Fault Tree Diagnosis System (FTDS) developed at NASA Ames Research Center. FTDS performs diagnostic reasoning using a fault tree reliability model as a knowledge base [Ref. 7]. The acyclic graph structure of the rule base produced by a matrix FMEA matches the fault tree structure required by FTDS.

FTDS bases its diagnoses on a record of normal and abnormal indicators for the system. It builds hypothesis constraint sets from the normal indicators and determines the basic causes of the abnormal indicators using a heuristic backward chaining search. FTDS is well suited for this telemetry monitoring task since the information it requires can be automatically recorded by the telemetry stream monitor.

The RAHF matrix FMEA analysis included additional information about failure detection methods, failure criticality, and failure recovery that proved very useful in the development of the monitoring and diagnosis system [Ref. 5]. The failure detection methods were used to develop the telemetry monitoring software, described in the next section, that connects the diagnosis system to the RAHF hardware. The matrix FMEA failure criticality and recovery information was used by FTDS to provide criticality data and corrective actions for any diagnosed failures or performance anomalies (Figure 2).

Telemetry Monitoring

The RAHF telemetry data was automatically monitored in real time and displayed to payload operations controllers on color graphic displays. The monitoring system scanned for any anomalies in the telemetry stream.

The RAHF matrix FMEA included detection methods for most of the effects listed in the analysis. These detection methods formed the basis of the telemetry monitoring system. The RAHF telemetry stream included temperatures and pressures in the RAHF, environmental control system status (e.g., heaters on or off), animal data (activity and water consumption) and various alarms triggered by sensors throughout the RAHF. The detection methods listed in the matrix FMEA allowed the relationship of effects of failures to these telemetry data points. For example, a detection method given to detect a leak in the animal drinking water supply system is to check for abnormally high water consumption counts for a given animal. If any of the abnormal conditions outlined in the matrix FMEA were detected in the telemetry stream, the information was be passed to the diagnosis system to find the cause of the problem.

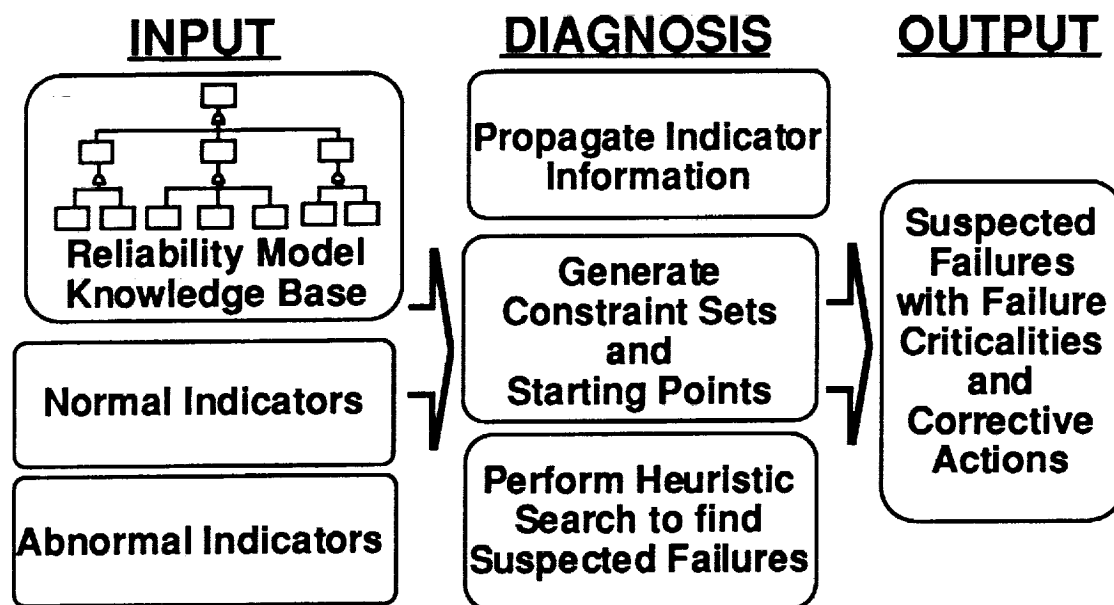


Figure 2: Augmented FTDS Algorithm

System Integration

The detection methods listed in the RAHF matrix FMEA have been added to the RAHF diagnostic knowledge base as consequents of the failure effect they detect (if effect then detect-method). This allows FTDS to reason backward from the detection method consequent to find the cause of the anomaly. If the monitoring system detects any anomalies in the RAHF telemetry stream, those anomalies will be sent to FTDS as abnormal indicators. FTDS will diagnose the cause of the anomalies and return the suspected failures, their criticality, and a list of corrective actions to overcome the failure.

The resulting diagnosis system is referred to as the RAD System (Real-Time Automated Diagnosis). The RAD was installed on a computer workstation in the payload telemetry monitoring area during the flight of the RAHF in October 1993. During flight operations the workstation displayed trend graphs of RAHF information, such as temperature, humidity, and animal activity. When anomalies occurred during RAHF system operation, the payload operations staff was immediately notified by the RAD System (with audio and visual alarms) and a diagnosis screen appeared on the workstation that presented the results of the FTDS diagnosis and recommended corrective actions. Provisions were made to allow diagnosis of conditions not covered by the telemetry (e.g., the Space Shuttle crew reports that the lights in the RAHF did not light when the daytime simulation was scheduled to start).

Conclusions

This research produced general and specific techniques for using traditional reliability models for automated diagnosis. By using these techniques an automated monitoring and diagnosis system like "The RAD" can be produced for any system that undergoes a matrix FMEA analysis. This could save a great deal of time and expense that would otherwise be devoted to knowledge acquisition and knowledge engineering activities. By using the matrix FMEA Methodology all of the performance issues were addressed, as well as all of the safety issues. Since the matrix FMEA contains performance information, the diagnostic system can monitor for performance anomalies as well as severe failures. The development of the RAD System has also provided insight into how reliability analysts can augment their analyses with detection methods, corrective actions and severity ratings to further facilitate diagnostic reasoning and failure recovery.

References

1. Barbour, Gilbert L., "Failure Modes and Effects Analysis by Matrix Method", *Proc. Annual Reliability Symposium*, January 1977, pp. 114-119.
2. Legg, John M., "Computerized Approach for Matrix Form FMEA", 1978 *IEEE Transactions on Reliability*, Vol. R-27, No. 4, October 1978, pp. 254-257.
3. Herrin, Stephanie A., "System Interface FMEA by Matrix Method" 1982 *Reliability and Maintainability Symposium*, Los Angeles, January, 1982, pp. 111-116.
4. Herrin, Stephanie A., "Using the Matrix FMEA Technique to Comply with IEC-WG9", 1982 *Eurocon Symposium*, North Holland Publishing Company, Lyngby, Denmark, June 1982, pp. 159-163.
5. Herrin, Stephanie A., "Maintainability Applications using the Matrix FMEA Technique," *IEEE Transactions on Reliability*, Vol. R-30, No. 3, August 1981, pp. 212-217.
6. Iverson, David L., Stephanie A. Herrin, "Real Time Automated Diagnosis Using Matrix Failure Modes and Effects Analysis", *Proceedings of the Sixth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*, Scotland, June, 1993.
7. Iverson, D.L. and F.A. Patterson-Hine, "Object-Oriented Fault-tree Models Applied to System Diagnosis," *Proc. of the SPIE Applications of Artificial Intelligence VIII conference*, Orlando, FL, Vol. 1293, April 1990.

